NASA
SPACE VEHICLE
DESIGN CRITERIA
(STRUCTURES)

NASA SP-8061

INTERACTION WITH UMBILICALS AND LAUNCH STAND

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOREWORD

NASA experience has indicated a need for uniform criteria for the design of space vehicles. Accordingly, criteria are being developed in the following areas of technology:

Environment

Structures

Guidance and Control

Chemical Propulsion.

Individual components of this work will be issued as separate monographs as soon as they are completed. A list of all published monographs in this series can be found at the end of this document.

These monographs are to be regarded as *guides* to the formulation of design requirements and specifications by NASA Centers and project offices.

This monograph was prepared under the cognizance of the Langley Research Center. The Task Manager was J. R. Hall. The author was R. D. Anschicks of Martin Marietta Corporation. A number of other individuals assisted in developing the material and reviewing the drafts. The technical adviser was J. D. Church of NASA Langley Research Center. In particular, the significant contributions made by J. George of The Boeing Company; D. S. Hackley of General Dynamics Corporation; W. G. Hample of TRW Systems Group/TRW Inc.; G. H. Ikola and W. O. Wolford of McDonnell Douglas Corporation; P. B. Mulcaire and D. J. Tenerelli of Lockheed Missiles & Space Company; and R. G. Urash of LTV Aerospace Corporation are hereby acknowledged.

NASA plans to update this monograph when need is established. Comments and recommended changes in the technical content are invited and should be forwarded to the attention of the Design Criteria Office, Langley Research Center, Hampton,Virginia 23365.

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INTERACTION WITH UMBILICALS AND LAUNCH STAND

1. INTRODUCTION

A space vehicle at the launch stand interacts in many ways with ground support equipment (GSE) during transportation, erection, checkout, and flight. Some of these interactions result in force or deflection being applied to the space-vehicle structure; others require structural penetrations and openings in the vehicle; still others occur when personnel and GSE perform functions within the vehicle.

None of these effects is likely to create particularly difficult problems for the structural designer of the vehicle if he is aware of them early in the design cycle. However, if vehicle-GSE interactions are revealed late in the program, ill-conceived interfaces may be developed, resulting in excessive weight and complexity, inadequate provisions for access, or vehicle failure. In one case, when the ground crew failed to rig the umbilical disconnect properly, a large launch vehicle was destroyed shortly after liftoff because of structure torn away on launch. Had the umbilicals been designed for fail-safe operation, the flight could have been saved despite the human error.

There is a great need for the vehicle designer to be aware of all vehicle-launch-stand GSE interactions to coordinate GSE requirements and to maintain understanding of the developing GSE design as it affects vehicle structural design. Often the vehicle structural designer and the GSE designer do not talk to each other until a design review or until a field problem reveals an incompatibility. Ironically, interfaces between companies are sometimes controlled more effectively than those within a company.

This monograph provides criteria and recommends practices to ensure compatible interfaces between space-vehicle structure and launch-stand GSE. Current practice is appraised, with emphasis on the proper consideration of interaction between the vehicle structure and launch-stand GSE. For simplicity and clarity, the monograph is divided into five subjects: (1) interface identification, (2) openings and penetrations, (3) umbilicals, (4) platforms and access ladders, and (5) structures and hard points.

For purposes of this monograph, launch-stand GSE includes access platforms, umbilicals, launch mounts, service towers, checkout equipment, tools, and all other mechanical interfaces at the launch stand. The space-vehicle structure includes launch-vehicle structure, spacecraft structure, and shroud structure.

Interactions with factory-to-launch-stand transportation and handling equipment receive only passing mention in this monograph because they are discussed in companion monographs in preparation on transportation and handling loads and on interaction with handling and transportation systems. Payload shrouds and fairings receive consideration here, but are to be covered more fully in a monograph on payload aerodynamic shrouds. Interactions between space-vehicle structure and the launch mount are covered in the monograph on transient loads from thrust excitation.

2. STATE OF THE ART

Design of structure to accommodate structural interactions with launch-stand GSE is so much a matter of common sense, good management techniques, and application of common stress-analysis methods after loading conditions are known that the state of the art must be considered rather fully developed. Identification of the interfaces and definition of the loading conditions, however, are not well established and require close attention to ensure successful results.

The state of the art of space-vehicle production, transportation, erection, and flight preparation requires extensive checkout of the operating systems at the launch site. These checkouts require many GSE interfaces with such space-vehicle structure as umbilicals, antenna "hats" for radiation containment, access openings, platform supports, and structure hard points.

2.1 Interface Identification

Aerospace organizations have generally progressed from reliance upon the alertness and integrity of individual designers for interface recognition and coordination to the use of functional-flow analysis by a systems or project organization to ensure such action. (Functional-flow analysis, of course, has many other applications in aerospace design; it is a widely used management tool in the industry.)

For indicating space-vehicle-structure/GSE interfaces, the typical functional-flow analysis begins with diagramming a gross flow chart showing the various functions involved in transportation, erection, servicing, testing, and launch. The chart is refined to successive levels of detail until all functions are clear. The basic principles of functional-flow diagrams, along with examples, are given in reference 1.

There are other tools to permit understanding and control of vehicle-structure/GSE interfaces. Detailed integration layouts identifying all equipment in and on a vehicle are widely used. On some low-cost programs, however, only the drawings used directly in production are made; thus, integration layouts would not be available.

Formal interface-control methods such as Interface Requirements Documents, Interface Specification Documents, and Interface Control Drawings are commonly used to define and control interfaces between contractors. Documents such as these are also used within a company on some programs. Formal design reviews held when concepts are defined, and again before release of production drawings, are also means of maintaining communication and understanding between design areas.

Layouts integrating the vehicle with its GSE surroundings have proven useful, too. Drawings like these can show, for example, the need for arrangement of antennas and guidance components for unobstructed line-of-sight contact with other vehicle or ground equipment.

Inevitably, some situations are not foreseen with the formal interface and control tools, and designers must always be on the alert for these situations. An example is the impingement of fire-fighting water on vehicle structure: a heavy stream of water could damage the structure it is being used to protect. Accordingly, the structural designer should be sure the GSE designer understands structural-limiting conditions when the GSE designer is developing ground equipment.

2.2 Structure Openings and Penetrations

Functional analysis indicates the basic functions requiring access into structure. This analysis leads to determination of the specific sizes, shapes, and mechanical and structural features of openings through the long-established design procedure of layouts, consultation with the designers involved, stress analysis, maintenance analysis, and production drawings. When the structure and installed equipment are too complex to be readily understood by layout alone, a mockup of a part of the space vehicle is often built for design development and verification.

Bolted doors that close structural openings are frequently part of the primary structure and carry primary loads (shear loads, at least). However, there are exceptions where the doors function only as closures and carry only normal aerodynamic loads. Hinged doors may be used for mounting components (to provide optimum accessibility) where those components can tolerate the environment.

Doors can be attached to structure with common threaded fasteners or patented fasteners with quick-locking and self-aligning features. Both types are in general use. Some doors are hinged, and some hinged doors close and latch as part of the launch umbilical-release sequence.

To prevent collapse, unpressurized liquid-propellant tanks and sealed compartments are designed with openings to balance internal pressures with changes in atmospheric pressure. The usual practice is to attach a GSE device which will pass air through a screen, filter, and desiccant system to ensure that the allowable pressure differential between the inside and outside of the tank or compartment is not exceeded.

2.3 Umbilicals

Umbilicals that disconnect automatically at launch have evolved to their present state of effectiveness through a difficult and tedious learning process. Knowledge of the interaction of these launch umbilicals with vehicle structure has increased along with the development of the launch umbilicals themselves. Although umbilical/structural systems of high reliability have been produced, the launch umbilical remains the detail likely to cause trouble in the interaction of space-vehicle structure and GSE, and bears most careful attention, especially when programs are manned by personnel who are not familiar with the system's development. Structural failure from umbilical-disconnect failure, overtorquing of umbilical connection, or impact of a disconnected umbilical can result from improper design or installation.

Umbilicals can be classified by function as:

1. Electrical.

2. Gas – high/low pressure and air conditioning.

3. Fluid – propellant, refrigerant, hydraulic.

Various successful approaches to launch-umbilical design have evolved at different aerospace firms. These approaches differ in placement of the umbilical (in a group or separately with individual actuation); in means of actuation (spring, pneumatic, or mechanical camming); and in means of triggering actuation (lanyard pull, gas, or electric unlatching). Various types of electrical launch-umbilical disconnects are discussed in reference 2.

One widely used approach, with perhaps the greatest impact on structures, is illustrated in figure 1. With this system, the ground portions of a group of umbilicals are attached to a plate which also incorporates a pneumatic-latching and cam-actuation device. The vehicle portions are attached to a plate that is permanently attached to the vehicle structure. The system illustrated uses pneumatic cam actuators (in the umbilical plate) as prime; mechanical cam actuators (hydraulic cylinder at the end of the lanyard) as secondary; and vehicle rise (lanyard and umbilical connectors) as backup disconnect modes. Furthermore, the ball-lock pin receptacle is designed to shear from the vehicle if the ball-lock pin jams.

Another approach to umbilical design is through the use of separate disconnects for each umbilical. These need not be closely grouped, but must be located in a favorable

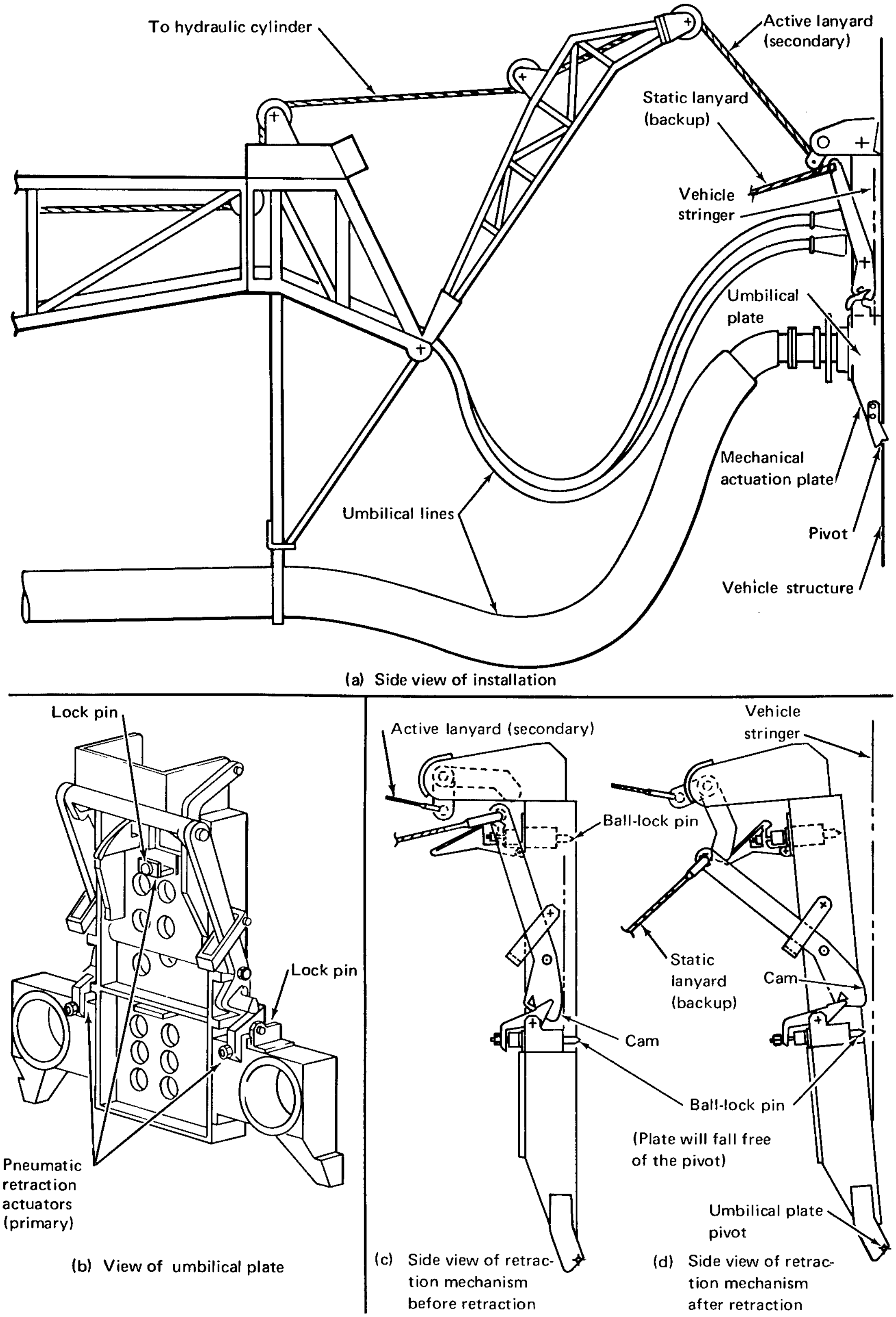

Figure 1. – Umbilical installation.

position for umbilicals and lanyards to reach an umbilical boom or service tower. Connectors of this type with a variety of actuating mechanisms are available as off-the-shelf hardware. Secondary and backup disconnect mechanisms have been incorporated into some of these designs. When a secondary disconnect system has been incorporated into an individual electrical umbilical, it has been found to improve reliability from about 0.995 to 0.999995. Connectors of this type are usually recessed below the skin line and covered with a hinged flap to protect the connector from aerodynamic heating and ionization.

To establish loads and verify operation, it has been found necessary to test launch umbilicals and the space-vehicle structure to which they are attached in a way that simulates the motions experienced during launch.

Not all umbilicals disconnect automatically at launch. When noncryogenic propellants are used, the propellant umbilical operations may be accomplished manually without difficulty. There is, however, the requirement for protection of the structure against the deleterious effects of propellant spills. Large launch vehicles have been designed to accommodate automatic reconnect fueling umbilicals.

Some vehicles have umbilical connections at their base. This practice simplifies or eliminates some of the umbilical problems associated with retraction and support of side-mounted umbilicals, but usually introduces other undesirable effects, such as additional vehicle weight and complexity.

Designers have become aware of many loading conditions imposed by umbilicals upon the vehicle structure. These range from the rather obvious loads from umbilical weight, connecting and separating, and line pressure to somewhat less obvious loads such as those resulting from swaying of the vehicle, wind-induced oscillations of umbilical lines, umbilical stiffness, opening and closing valves, and vibration. Designers are also aware of the effects of repetitive loading as, for example, in repeated demonstrations of functional capabilities throughout the service life.

2.4 Platforms and Access Ladders

Most operations performed on a space vehicle at the launch site are conducted from platforms outside the vehicle and not in contact with it. These platforms often have flexible "boots" which close the gap between the platform and the vehicle structure to provide environmental seals and to catch small objects which might be dropped. There are few "hard" interfaces between these external platforms and the vehicle, and space-envelope clearance must be maintained between the vehicle and platform.

The probability of large deflections or loads from extreme forces, such as hurricanes or earthquakes, and the cost to each program in resources and vehicle weight to provide for such a probability must be evaluated, considering (1) probability of occurrence, (2) possibility of taking protective action, (3) requirements for launch on time, and (4) launch sites. It has been the practice to design for strong winds up to a specified speed; for launch from Kennedy Space Center, for example, spacecraft are designed to withstand winds of 64.4 knots (33.13 m/sec), the speed measured at a reference level of 60 ft (18.3 m) (ref. 3). It has also been the practice to secure against hurricane-force winds with temporary restraints, but to accept the low risk of seismic disturbances.

It has never been practicable to gain access from external platforms to all points in a large space vehicle for service or checkout. Internal platforms supported from vehicle structure or cantilevered from external structure are used to provide supplementary access. Vehicle-supported platforms are usually supported from frames or stringers, but some have been designed to rest on tank domes and, accordingly, are contoured to the dome shape. The hazards of handling internal platforms while they are being installed and removed, and of personnel working within the vehicle, make vehicle-structure-supported platforms a somewhat undesirable alternative to completely external platforms.

2.5 Structure Hard Points

Concentrated loads are often encountered while the vehicle and its components are being supported on the launch stand and handled. Hard points provided for vehicle handling are usually found in vehicle structural joints between tank cylinder and dome, or in structure designed for field-splicing sections of launch vehicles. Designers have generally been successful in designing GSE which does not require extensive additional vehicle structure for the sole purpose of sustaining loads introduced by GSE.

The method of handling and support of solid-propellant rocket motors sometimes requires special attention in design to be sure deformations do not cause separation of propellant or liner. This is especially true of thin shell cases, notably the glass filament-wound type.

The hard points that support the vehicle on the launch stand receive the greatest load, and are usually associated with engine-truss hard points and the vehicle motion-damper arm attachment. Some vehicles are held down after engine ignition and are not freed to lift off until specified conditions of thrust and time are met. Some are not held down and are free to lift off when thrust exceeds weight.

Some hold-down systems make direct use of ordnance devices for release, and some use retractable mechanisms for both hold-down and release. While the mechanism itself may be quite complicated, the vehicle/GSE interface for the retractable device is relatively simple, requiring only a provision for adequate space for the mechanism to hold and operate, and enough strength to sustain the loads. The use of ordnance devices usually requires a means of catching flying parts and absorbing their energy. Such means are not necessarily provided as part of the primary structure, but they can be. The analysis of a hold-down system includes a consideration of the dynamic response of the launch mount and its substructure to thrust buildup and possible thrust cutoff (ref. 4 and the planned monograph on transient loads from thrust excitation).

Coordinated tooling is often used on launch-vehicle and GSE structure to facilitate matching. GSE attach points are usually adjustable to accommodate manufacturing tolerances and acceptable deformation due to handling loads.

Vehicle-support hard-point design must be compatible with the prescribed condition for maximum ground wind and seismic disturbance discussed under Section 2.4.

3. CRITERIA

The interfaces between the space-vehicle structure and launch-stand GSE shall allow all ground-handling, test, servicing, repair, and launch operations to be conducted without degradation of structural integrity. Interface control shall be provided to ensure that structural integrity is not compromised, and that

- All interfaces are identified.
- Openings are properly sized.
- Umbilical interfaces will accept all applied loads.
- Specified clearance will be maintained between vehicle structure and external platforms, and the structural interface with internal platforms will accept all applied loads.
- Structural hard points will accept all loads imposed by GSE with allowable deflection.
- Vehicle structure is not sized by loads or deflections imposed by launch-stand GSE, insofar as practical.

3.1 Interface Identification

All interfaces between launch-vehicle structure and launch-stand GSE shall be identified and accounted for.

3.2 Structure Openings and Penetrations

The space-vehicle structure shall accommodate penetrations and openings without degradation of structural integrity. The effect on structure of the removal of doors or covers during erection, assembly, and checkout shall be determined, and necessary operating restrictions provided. Restrictions shall be prominently marked on fixed structure adjacent to such doors and on the doors themselves, and shall be included in the procedures and checklists.

Access openings in the structure shall account for the following:

- The size of the largest replaceable unit plus clearance for handling
- Personnel entry
- Installation of internal work platforms
- Multiple removal and replacement cycles
- Sufficient space to make and inspect connections, leak-test joints, install and check ordnance, operate tools, read meters, or to perform any other operation required at that opening

Free-breathing devices shall be provided, as required, to vent tanks and closed spaces to accommodate changes in temperature and in atmospheric pressure at the launch stand.

3.3 Umbilicals

The space-vehicle structure shall accept without degradation of structural and functional integrity the loads and motions resulting from

- The weight and stiffness of the umbilicals
- The act of connecting the umbilicals
- Swaying of the vehicle while it is attached to the umbilicals
- Wind load on umbilical lines and wind-induced oscillation of umbilical lines
- Opening and closing of valves
- Umbilical line pressure
- Vibration (with umbilicals still attached)

- Normal and fail-safe modes of separation of the umbilical from the vehicle

- Repeated demonstrations of functional capabilities

Umbilical-disconnect and -retraction mechanisms shall be designed fail-safe to prevent failure of the primary system from causing physical or functional damage to the space vehicle. Connectors shall be designed so they cannot be improperly connected.

3.4 Platforms and Access Ladders

Sufficient clearance shall be maintained between space-vehicle structure and exterior platforms and access ladders to allow for the following:

- Space-vehicle flyout envelope

- Space-vehicle and/or GSE-structure deflection caused by a specified design wind

- Space-vehicle misalignment resulting from manufacturing tolerances, launch-mount misalignment, and service-tower construction tolerances

The space-vehicle structure shall accept without degradation of structural integrity the loads and deflections resulting from

- Installation and removal of interior platforms
- The weight of interior platforms and of personnel and equipment on them
- The dynamic effect of operations conducted on and from the platform
- Service arm access platforms that lock to the vehicle

3.5 Structure Hard Points

The space-vehicle structure shall include hard points capable of accepting, without degradation of structural or functional integrity, loads and deflections imposed by launch-stand GSE during lifting, rolling, turning, restraining, and support of the vehicle under all static and dynamic load conditions, including a specified maximum wind condition.

3.6 Tests

Demonstrations and tests shall be performed to verify the structural adequacy of the space-vehicle interfaces with the launch-stand GSE. (In this context, *demonstrations* refer to routine operations performed for each flight, and *tests* refer to the initial proof of capability, including the instrumentation, accumulation, reduction, interpretation, and reporting of data.)

The adequacy of structural openings to accommodate personnel and equipment shall be tested before shipment of the first production article.

Structural/functional tests and demonstrations of all interfaces between space-vehicle structure and umbilicals shall be performed to verify structural and functional adequacy under primary and fail-safe separation modes.

The adequacy of platforms and access ladders to provide support for personnel and equipment without inducing detrimental loads or deflections shall be tested.

The structural tests shall include load conditions that prove the capability of the vehicle structure to carry loads imposed by launch-stand GSE.

4. RECOMMENDED PRACTICES

Every effort should be made to anticipate GSE-vehicle interactions as early as possible in the establishment of the configuration. Consideration of these interactions should continue throughout the design cycle.

Early definition of the GSE-vehicle interactions likely to influence design will result in benefits in the form of a lighter, more efficient design. For example, dual-function design might employ shear panels that double as equipment enclosures or access-support structure; platforms required by GSE might also be used to provide subsystem support. Structure which satisfies GSE load requirements can also provide stabilization of primary structure. Grouping of access, maintenance, and checkout points in one quadrant along the vehicle length would simplify GSE design. Locating equipment on hinged panels provides easy access where environmental constraints permit.

The payload or the spacecraft usually contains sensitive equipment and materials requiring special environmental control for off-pad servicing or on-pad protection. These sensitive subsystems or units should be grouped so that ground servicing can be provided by the smallest amount of equipment. Similarly, every effort should be made to avoid space-vehicle designs that result in unnecessarily restrictive environments for a long period (e.g., between manufacture and launch) or components sensitive to a unidirectional attitude (e.g., always vertical).

4.1 Interface Identification

Functional-flow analysis should be the basic tool used in identifying and understanding interactions between space-vehicle structure and GSE. Interface Control Drawings, Interface Requirements Documents, and Interface Specification Documents are excellent for control of these interfaces. Design reviews of GSE and of space-vehicle structure, held as design progresses and before release of drawings for production of hardware, are also effective means of coordination.

Regardless of which tools are used, a formal procedure should be established which invests an individual or organization with specific responsibility and authority to identify and resolve interactions of the total space-vehicle structure/GSE system.

4.2 Structure Openings and Penetrations

Identification of the interactions will indicate the need for structural openings and penetrations. The analysis of structure should account for the effect of removing or unfastening doors for ground operations when the vehicle is at the launch stand. Sequence of loading conditions must be determined to define the proper restrictions on door unfastening and removal. Some of the interactions which are to be accounted for are (1) size of opening based upon size of largest replaceable unit, plus handling clearance, (2) personnel-entry provisions and clearance geometry, and (3) installation-clearance requirements for internal work platforms. Fastener wear-out considerations should include the effect of gaining access to accomplish multiple equipment removal and replacement. Sufficient space should be provided in the access openings to accomplish the following actions: (1) make and inspect connections; (2) leak-test the joints, (3) install and check ordnance, (4) operate tools, (5) read meters, and (6) perform any other operation required at that opening. Service lines should not be routed through personnel-access openings.

As an aid to the design effort, a full-size mockup of the vehicle should be constructed, reviewed, and critiqued, and all known operations performed for complex equipment installations. The mockup should include wiring and tubing, as well as equipment and structure. If GSE to be used in the area is not available, it should also be mocked up.

Free-breathing devices for tanks should be interchangeable as transportation and launch-stand hardware to minimize the cost, the number of interfaces, and the opportunity for errors. When it is necessary to design a special configuration for the vehicle on the stand, the designer should try to achieve maximum interchangeability with transportation hardware.

Components of equipment requiring special environmental control should be grouped to minimize the number of openings, protective devices, and other special features needed to provide this control.

4.3 Umbilicals

Umbilicals should be defined early in a program through use of a functional analysis. Wherever possible, umbilicals that are disconnected before launch should be used in preference to launch umbilicals so it will not be necessary to design structure for the secondary disconnect and fail-safe mode forces acting with the launch umbilicals. Umbilical mechanisms should have force, torque, and operating characteristics that are known or can be determined by test. Launch umbilicals should have secondary or backup disconnect mechanisms and should be designed to shear from the vehicle before damage can be caused.

The launch-vehicle structure should be analyzed and designed for the loads resulting from the umbilical forces due to weight, connections, vehicle sway, wind load and induced oscillations, opening and closing of valves, line pressure, vibration, vehicle separation, and repeated demonstrations of functional capabilities.

Development and acceptance tests should be completed before the first operational usage; demonstrations of functional capability should be made before each launch.

Structure should be protected from the corrosive effect of liquid spills from disconnected umbilicals by protective coatings, by the elimination of traps for gases and liquids, and by self-sealing umbilical disconnects.

4.4 Platforms and Access Ladders

Early identification of access requirements through use of functional analysis and maintenance analysis will help direct efforts toward arranging equipment for accessibility from outside the vehicle. Whenever possible, access platforms should be supported from the ground or from structure other than that of the vehicle.

Under some circumstances, it may be possible to use the vehicle structure itself as an access platform. Adjacent areas that cannot be used as access platforms should be so identified on the structure.

Exterior platforms cantilevered to provide a working surface within the vehicle or platforms supported by vehicle structure are not desirable. Where vehicle-supported platforms are used, every effort should be made to use basic vehicle structure for support, and to make the platform relatively lightweight, easy to install, free from dangerous protuberances, and capable of being locked in place. Clearances between external platforms, booms, towers, and the launch vehicle should be calculated for the effects of maximum wind.

4.5 Structure Hard Points

The primary structural system of the vehicle should be so designed that it can be used for GSE-interface hard points, when possible. When the hard points of the vehicle structure are not adequate, the GSE interface should provide a distributed load. Handling rings and belt slings distribute the load and should be applied at frame locations. Vehicle-support points are best located on the part of the vehicle structure that supports engine loads.

Absorption of energy from explosively operated release devices should be accomplished by shock-absorbing devices which are not part of the primary structure.

Analysis of loads at the vehicle-support-point interface should include the dynamic response of the stand, as well as that of the vehicle.

Master tooling should be used to coordinate vehicle-structure/GSE hard points.

4.6 Tests

Tests and demonstrations performed during the development, qualification, and acceptance of the space vehicle should include, but not be limited to, the following practices:

- Confirm that the openings, penetrations, platforms, and access ladders are adequate by determining the time to accomplish critical tasks such as recycling, replacement, refurbishment, or repair.

- Confirm the compatibility of internal access platforms with vehicle structure as early in the program as possible. Use of mockups for GSE verification is highly recommended.

- Confirm the design loads induced at the space-vehicle interface with the launch-stand GSE, and confirm that the deflections, loads, and stresses are within acceptable limits.

- Determine the dynamic characteristics of separating components, particularly umbilicals. When vehicle rise is a factor in umbilical separation, it and the elastic properties of the separating components should be simulated.

- Confirm the functional adequacy of interfacing components by repetitive testing. The anticipated number of uses for mated components, as well as the cumulative uses on successive vehicles, should indicate the minimum number of test repetitions needed to demonstrate functional adequacy. The number and effect of component matings before assembly on the launch stand should be accounted for in defining these tests.

- Confirm acceptable dynamics and functional characteristics of mating components over the entire range of anticipated environmental conditions, including vibration, effects of wind velocity and gusts, temperature, and sun exposure. The physical properties and interface integrity of long, heavy umbilicals are particularly subject to variation by the elements and by engine-induced vibrations.

- Demonstrate the functional integrity of umbilical systems for each space vehicle.

- Confirm the adequacy of the adjustment range for equipment which is adjustable, such as umbilical systems and the vehicle tie-down devices.

- When vehicle-GSE design incorporates primary and secondary modes of operation, such as in umbilicals, test both modes thoroughly.

- Confirm compatibility of the launch-stand GSE with the launch vehicle at the earliest possible time. Tooling may be used to confirm mating of critical components. The use of mockup for vehicle-GSE compatibility tests is recommended. Time should be allowed in the stand-acceptance schedule plan to confirm compatibility of GSE with the first production vehicle.

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